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EM20
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Fracture Control Requirements for Composite and Bonded Vehicle and Payload Structures

Abstract

The document presents a minimum set of fracture control requirements to be used across MSFC programs in designing and assessing composite and bonded structures. The scope includes manned launch, retrieval, transfer, and landing vehicles, space habitats, and payloads or experiments that are launched, retrieved, stored, or operated during any portion of a manned spaceflight mission. It is applicable to in-house and contract activities. The requirements apply to fiber reinforced polymer matrix composites, sandwich construction (bonded metallic and nonmetallic), and bonds between metallic or composite parts fall within the scope of this document.

Fracture Control Requirements for Composite and Bonded Vehicle and Payload Structures

MSFC-RQMT-3479

Why Develop a New Requirements Document?

- Current requirements are top level or specific to shuttle payloads.
  - NASA-STD-5007 top level requirement that imposes fracture control on all manned spaceflight hardware.
    - Composites addressed at very top level.
  - NASA-STD-5003 imposes fracture control on payloads for the space shuttle.
    - Imposes fracture control on composite and bonded structures.
    - Silent on many important issues such as post proof NDE, residual strength, and reuse.
    - Not adequate for or directly applicable to next generation of composite spacecraft.

MSFC-RQMT- 3479 Scope

- Hardware scope.
  - Manned spaceflight hardware including manned launch, retrieval, transport, and landing vehicles, space habitats, and payloads that are launched, retrieved, stored, or operated during any portion of a manned spaceflight mission.
- Materials/structures types.
  - Covered by new standard:
    - Polymer matrix composites.
    - Sandwich construction.
    - Bonded metallics, bonded composites, or bonded metallic-composite.
  - Specifically excluded by new standard:
    - Metal and ceramic matrix composites.
    - Foam.
    - Flexible inflatable structures.
    - Liquid rocket engines.
    - Solid propellants.

MSFC- RQMT-3479 Development Approach

- Review other requirements in addition to NASA ones:
  - Aircraft – Military – JSSG 2006
  - Aircraft – Civil – FARs/MIL-HDBK-17F
  - General literature
- Cast new requirements in the framework and language of existing NASA fracture control requirements.
- Address the shortcomings of existing NASA fracture control requirements.
- Rely on ANSI/AIAA S-081-2000 for COPVs.
- Refer to MIL-HDBK-17F for specific methodologies.

MSFC-RQMT-3479 Development History

- Review of existing fracture control practices completed in 2003.
- First draft of requirements issued in March of 2004.
- Continued to develop the requirements with the NASA Facture Control Panel input during 2004 and 2005.
  - Panel has representatives from all NASA Centers, ESA, NASDA, and the Space and Missile Center of the Air Force.
- Issued as a draft MSFC requirements document, MSFC-RQMT-3479, October 2005. Continued to develop within EM20.
- The NASA Fracture Control Panel decided at the June 2006 meeting to refer to MSFC-RQMT-3479 for composites in NASA-STD-5019.
- MSFC-RQMT-3479 published June 29, 2006.

Goals for MSFC-RQMT-3479

- Ultimately we would like to publish a NASA requirements document for fracture control of composite structures.
- We consider MSFC-RQMT-3479 a first step in developing a NASA document..
- It is recognized that it is not a perfect document and it is expected that the requirements will evolve with use.
  - We will continue to work with the NASA Fracture Control Panel and the NASA community to evolve the requirements.
- During document development, it became apparent that if we wait for everybody to be "comfortable", it would be years before we have a released document.
- We felt impending applications dictated that we publish our "best effort" now.
  - With MSFC-RQMT-3479, we are positioned to be responsive to future hardware developments using composites.

Examples of the MSFC-RQMT-3479 Criteria

Classification of Composite Parts and Bonds for Fracture Control

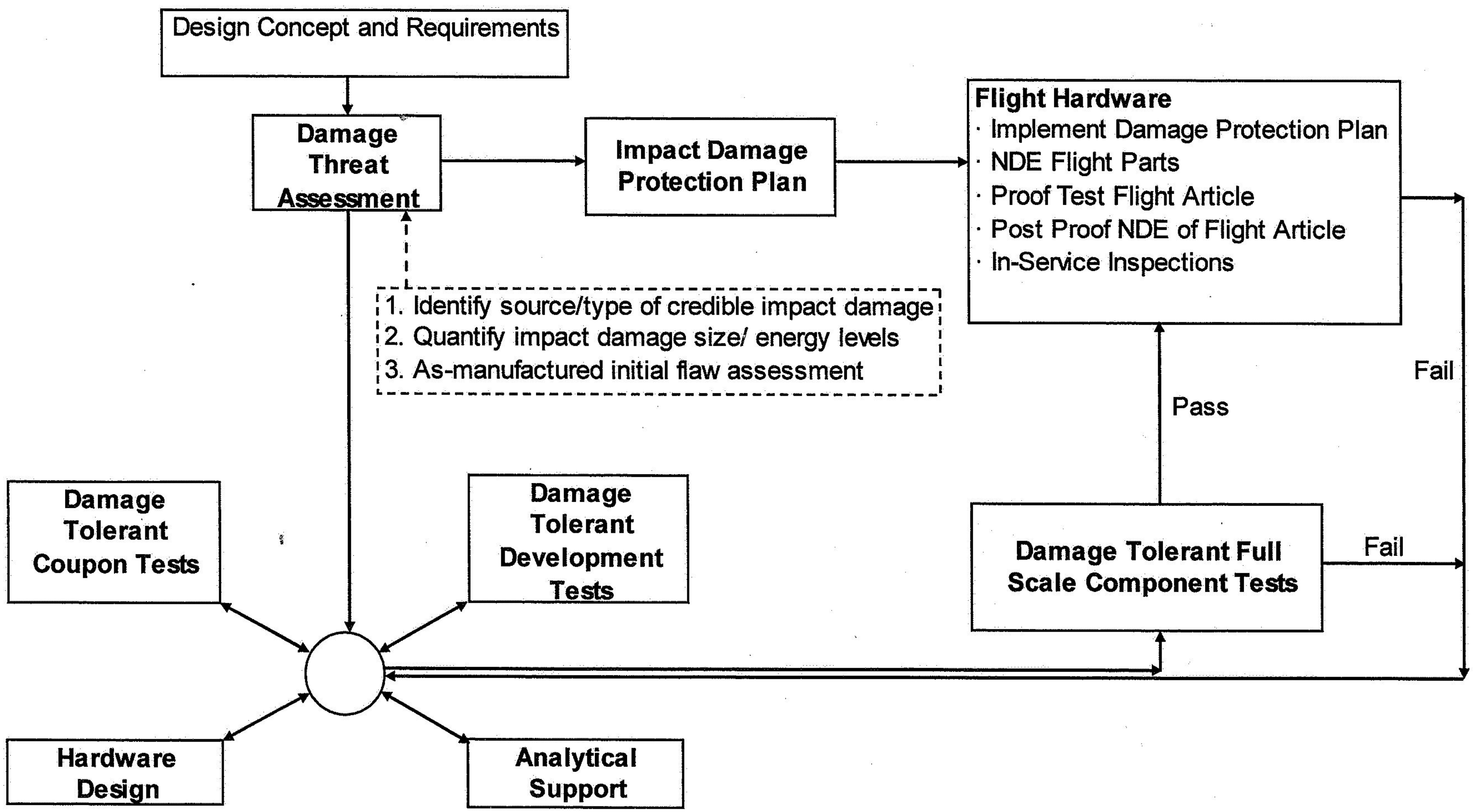
A part (or bond) is fracture critical if its failure due to the presence of a flaw would result in a catastrophic hazard. All composite parts and bonds shall be classified according to the following:

Exempt
- Non-structural and no safety critical function

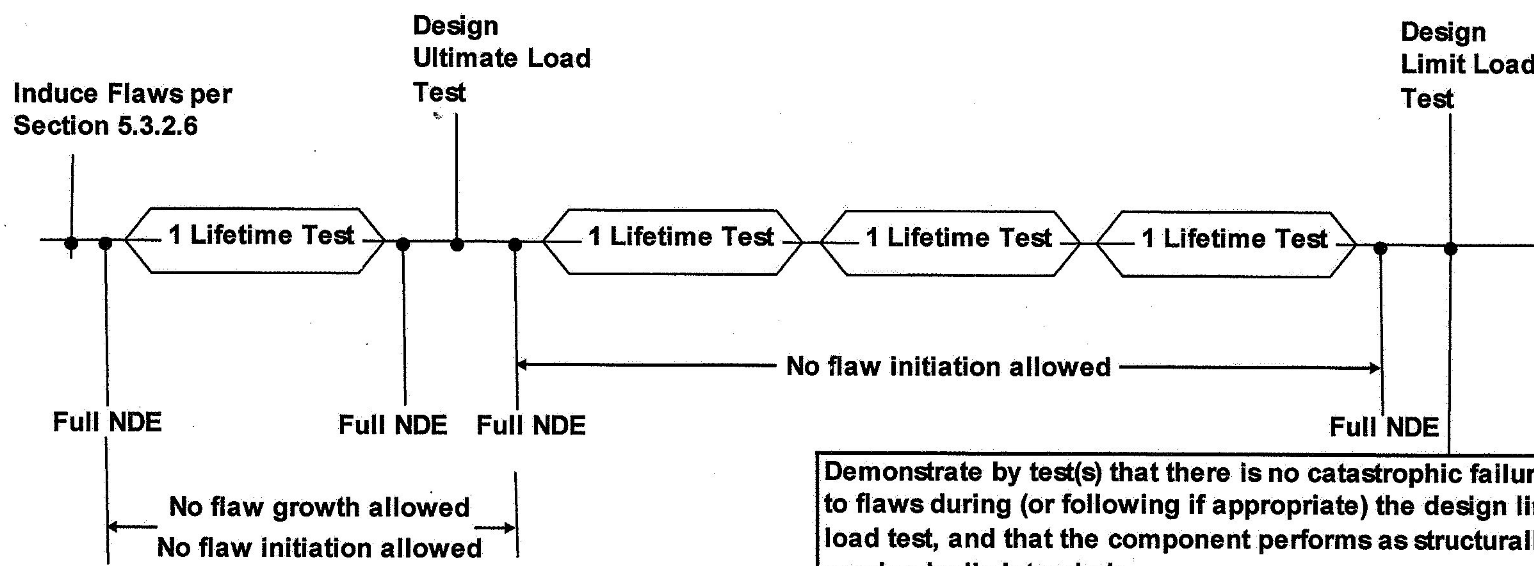
Non-Fracture Critical
- Low released mass
- Fail safe
- Contained
- Low risk
- Non-hazardous leak before burst (NHLBB)

Fracture Critical
- Proofed
- Damage tolerant

Steps in Establishing Damage Tolerance



Damage Tolerant Full-Scale Component Test



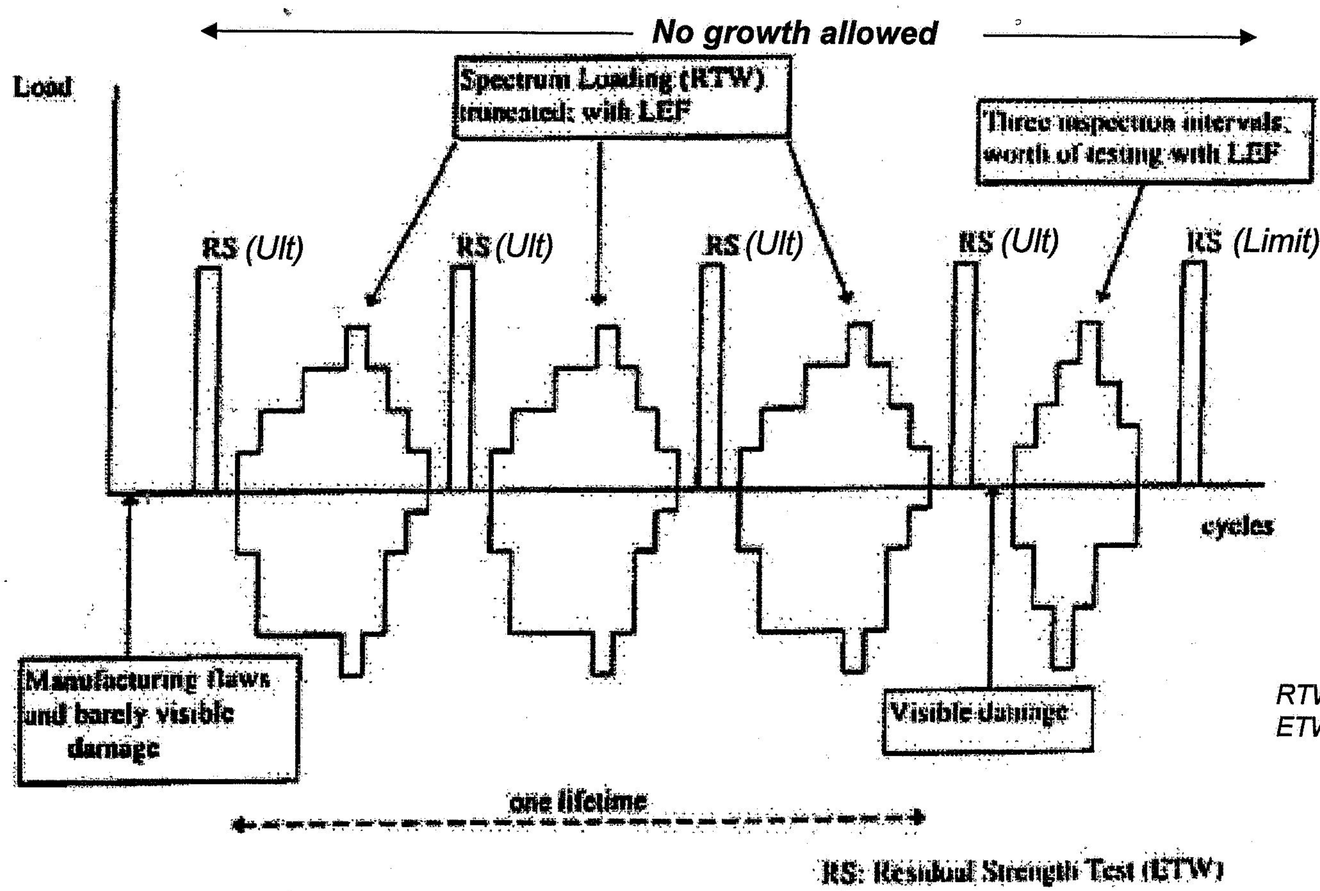
Demonstrate by test(s) that there is no catastrophic failure due to flaws during (or following if appropriate) the design limit load test, and that the component performs as structurally and mechanically intended:

> no structural failure, burst, etc.
> no catastrophic leak due to flaws
> no catastrophic mechanical malfunction
> structurally and mechanically peforms design function

Application/ Examples -MIL-HDBK-17-3F – Figure 7.9.1.6

Rotocraft (Sikorsky)

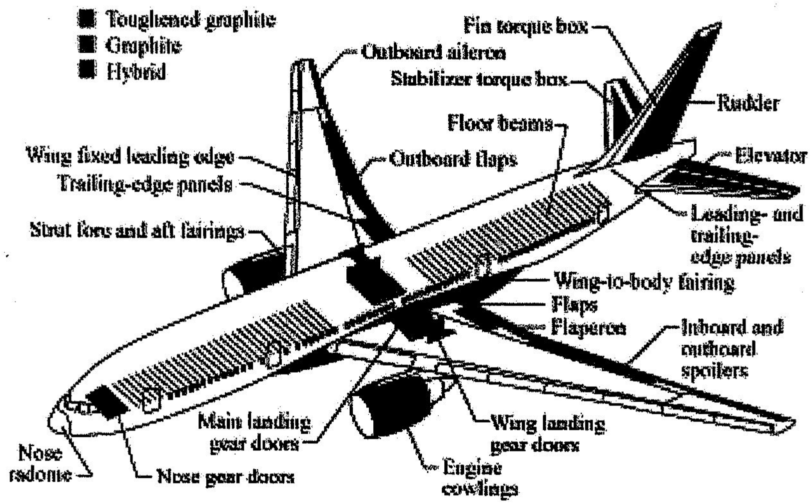
Damage Tolerant Certification Procedure Schematic



RTW = Room Temp - Wet
ETW = Elevated Temp - Wet

Boeing 777 – Composite Usage

- Empennage Torque Boxes
- Passenger Floor Beams
- Aero Fairings and Other Secondary Structures
- 9% of Structural Weight

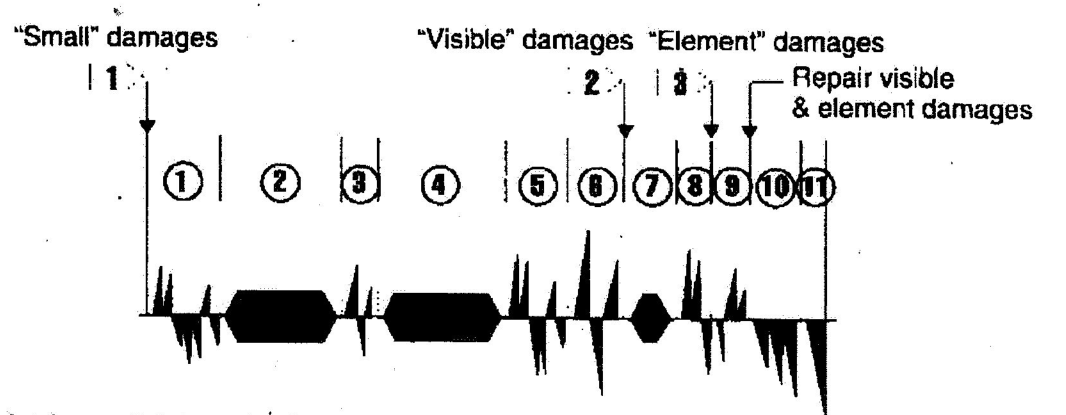


Source: oae.larc.nasa.gov

Application/ Examples -MIL-HDBK-17-3F – Section 7.9.2

Commercial Aircraft – Boeing 777 Empennage Torque Boxes

Preproduction Horizontal Stabilizer Test Sequence – Demonstrate "No Growth"



Apply small damages 1

1. 60% design limit strain survey - 6 conditions
   Flight test instrumentation check-out
2. Fatigue spectrum - 1 lifetime including load enhancement factor
3. 60% design limit strain survey - 3 conditions
4. Fatigue spectrum - 1 lifetime including load enhancement factor
5. Design limit strain survey - 6 conditions
6. * Design ultimate loads - 3 conditions

Apply visible impact damages 2

7. Fatigue spectrum - including load enhancement factor - two inspection periods
8. Fail safe (limit) loads - 3 conditions

Apply element damages 3

9. "Get home" loads (approx 70% limit) - 3 conditions

Repair visible and element damages

10. Design ultimate loads - 3 conditions
11. Destruction test

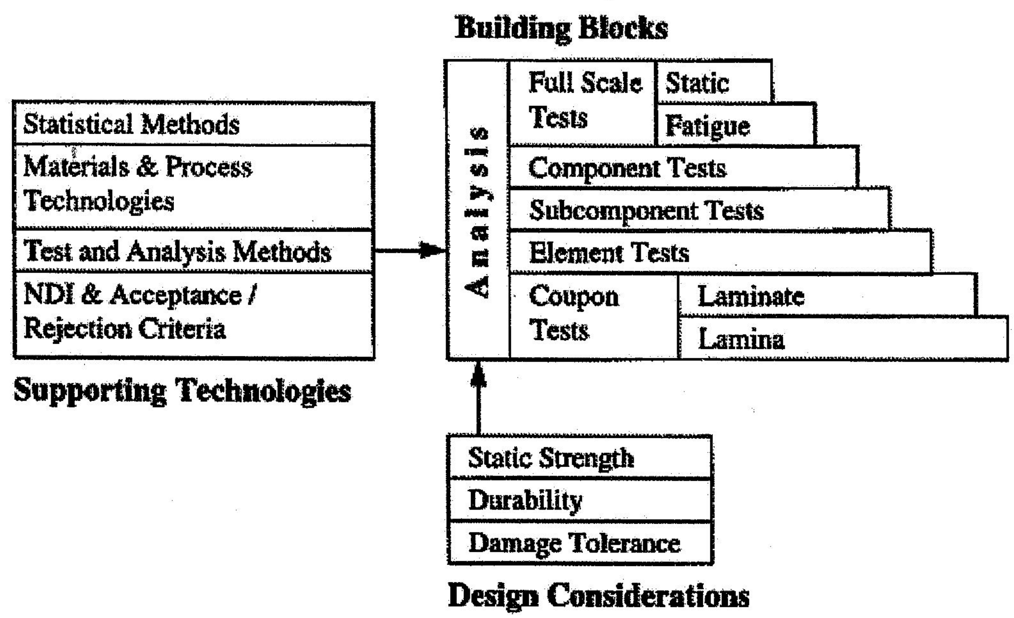
1 "Small" damages - impacts at an energy level less than 1200 in-lb whose resulting damage is visible at a distance of less than 5 feet.

2 "Visible" damages - readily detectable during the scheduled inspection plan.

3 "Element" damages - complete or partial failure of one or more structural units.

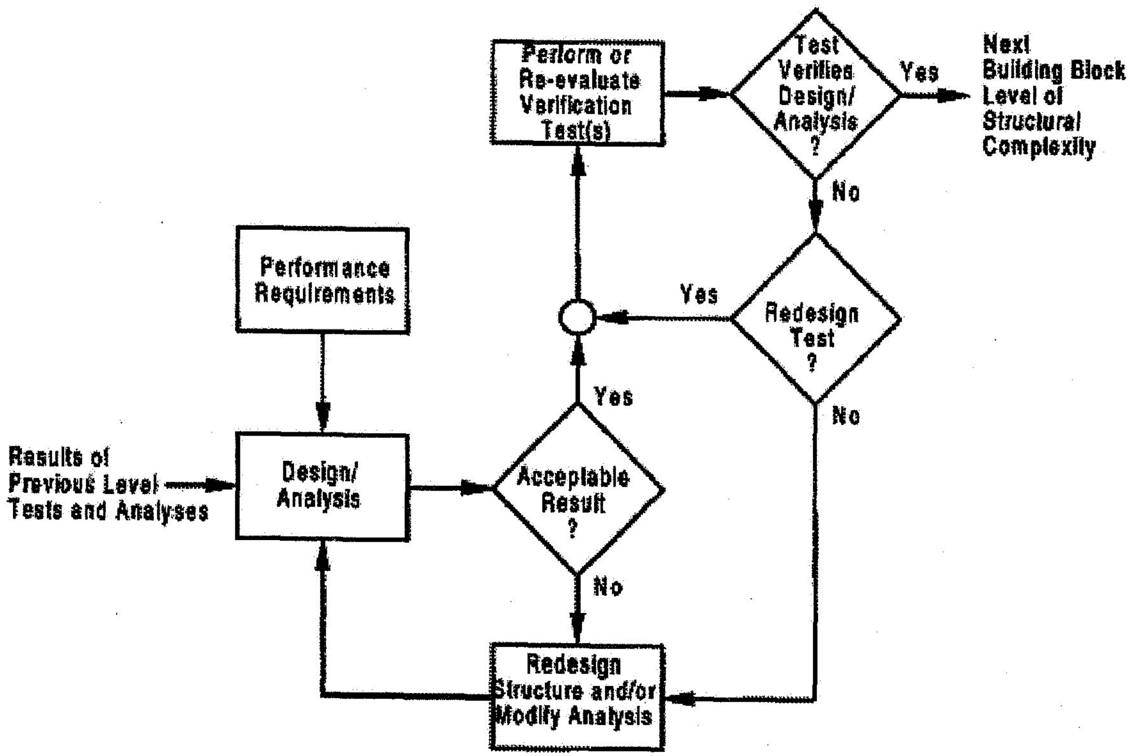
Building Block Approach
(Adapted from Mil-HDBK-17)

- Used in military and civil aircraft composite design.
- Stepped approach from simplest structural elements to final product.
- All disciplines involved in developing appropriate technologies during each step.
- Cost efficiency achieved by including more articles in lower level blocks.
- Reduces the probability that significant surprises will materialize near the end of the program.
- Technical and cost risk tolerance determine extent of the blocks included in a particular program.



Building Block Approach
(Adapted from Mil-HDBK-17)

Assessment process for each block



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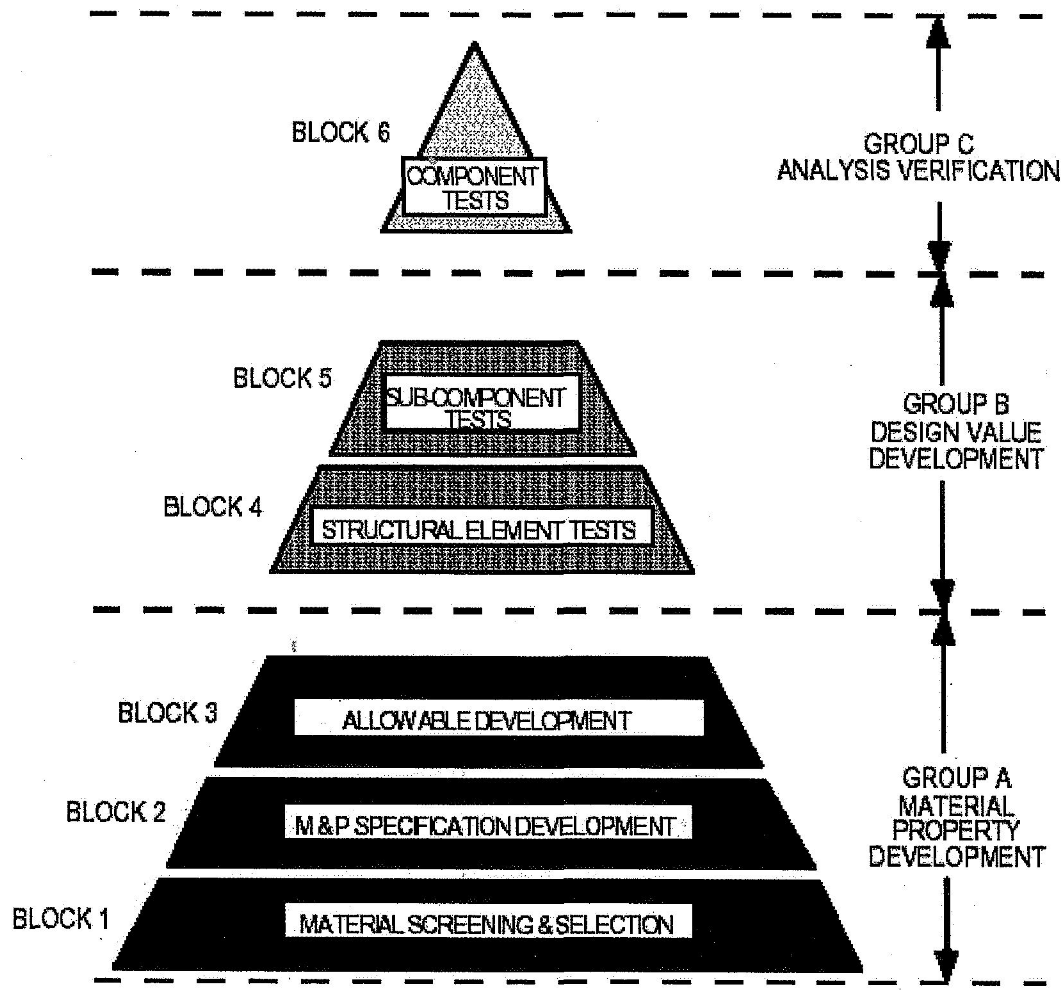

Verification of design and analysis methodology on full scale components representative of the actual hardware. Flight loads and BC's simulated.Test article thoroughly instrumented. Components include horizontal stabilizers, empennages, etc.

Sections of a component that allow load redistribution around defects. Biaxial loading similar to actual case. Tests include stiffened panels (with cutouts), deep beam shear, etc.

Local repeated structural details, bolted joints, stiffeners, angle clips, sandwich structure, etc. - generic loads.

Develop allowables (A/B basis).

Validate specs. Develop preliminary allowables.

Evaluate material options, select candidate(s).

All blocks with and w/o defects, static and fatigue loading in appropriate environment

Building Block Approach
(Adapted from Mil-HDBK-17)

Example of subcomponent (Block 5) tests for Boeing 777 empennage.
Includes flawed and unflawed specimens.

Test Type	Number of Tests
Bolted Joints (Major Splices)	110
Rib Details	90
Spar Chord Crippling	50
Skin/Stringer Compression Panels	26
Skin/Stringer Tension Panels	4
Skin/Stringer Shear/Compression	6
Skin/Stringer Repair Panels	6
Skin Splice Panels	2
Stringer Runouts	4
Spar Shear Beams	6
Total	**305**

Example of Technical Issue

No-growth Threshold Strain

- The no-growth threshold strain is the strain level below which flaws of interest do not grow in 10^6 (10^8 for rotating hardware) cycles at the applicable load ratio.
- The no-growth threshold strain is establish by test.
- This strain is needed for the low risk classification or in the truncation of tests spectra.
- The issue was:
  - Can we specify a default value, say "some" percent of ultimate strength that would be applicable for all situations and avoid testing to establish the no-growth threshold strain?

Review of the Literature

- Threshold strains not addressed in ASTM standards.
- Literature confusing, can be misleading and easily misunderstood.
- "Threshold" may refer to undamaged state as in "endurance limit".
- Thresholds are sometimes addressed as percent of static undamaged strength and sometimes as percent of strength after damage. Also addressed as a percent of the critical strain energy release rate.
- Strain range (R) is important as well as strain magnitude.
- Numbers quoted as thresholds are generally application specific.
- Look at a specific case to gain some insight:
  - Han, H. T., Mitrovic, M., and Turkgenc, O., "The effects of Loading Parameters on Fatigue of Composite Laminates: Part III", DOT/FAA/AR-99/22, June 1999.

FRACTURE CONTROL REQUIREMENTS *for* COMPOSITE and BONDED VEHICLE and PAYLOAD STRUCTURES

MSFC Engineering Directorate
EM20 Damage Tolerance Assessment Branch

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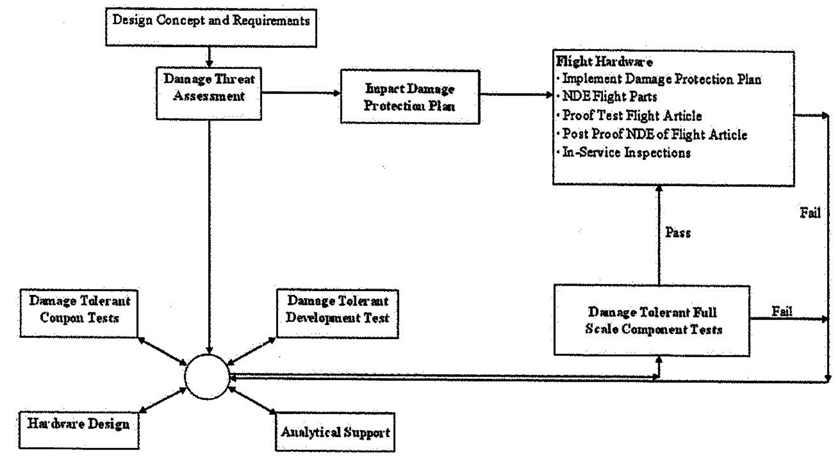
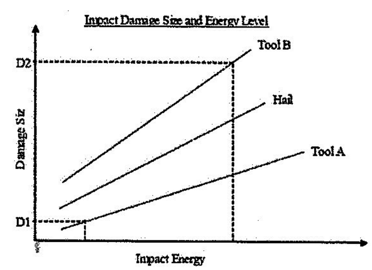
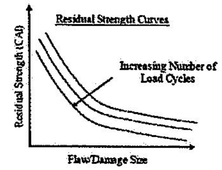


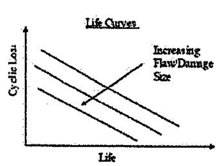
Impact Damage Size & Coupon Test Schematics

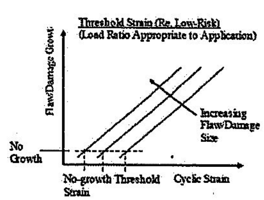
- Determine impact damage sizes.
- Each impactor, material, layup, design, and construction type to be addressed.
- Characteristic impact damage size range is [D1, D2].



- Produce design curves/data to be used in designing the flight hardware and determine a threshold strain for low risk classifications.
- Each flaw/damage type, material, layup, construction type to be addressed.







Damage Tolerant Full-Scale Component Test